APPENDIX E
Space Physics

INTRODUCTION

The study of the physics of our space environment has been one of the most rewarding areas of space science. This study has been carried out thus far almost entirely with automated satellites, and should continue. However, as an increasing manned capability develops, we can see great potential advantages accruing to certain areas of space-physics activity (refs. 1-6).

In this paper we will assume that a substantial manned space station capability will be available in the post-1975 period. We expect large-weight, frequent-supply missions, long lifetime (not necessarily manned continuously), and high reliability. The astronaut will add a degree of versatility unattainable by other systems; while some experiments can be performed automatically, the presence of man is essential in the early stages. Other experiments require a degree of interaction with the experimental subject that only a scientist can provide.

We will consider here the most important of the foreseeable physics research areas that will benefit from the available manned-station capabilities: (1) high-energy and cosmic ray physics; (2) behavior of solids, liquids, and gases in zero-gravity; (3) relativity, cosmology, and gravitation physics; (4) micrometeoroid measurements, gegenschein, zodiacal light, and matter at the libration points; and (5) magnetospheric physics and study of the trapped radiation belts and aurora, wave propagation in a dilute plasma, and interaction of the solar wind with the Moon.

These fields will be discussed briefly, with reference sources cited for more detailed information.

HIGH-ENERGY AND COSMIC RAY PHYSICS

The electromagnetic radiation that reaches the solar system has been one of the most important tools for man's quest into the origin, behavior, and perhaps even the end of the universe to which he belongs. Together with this radiation we are reached by a steady flux of particles, some of them with energies higher than are envisioned as ever being attainable on Earth. The study of the energy spectrum (extending into the 10^{20} eV region), antimatter and nuclear composition, charge spectrum, and directionality of this radiation is expected to yield invaluable insights into the age and origin of the universe and of the elements, nuclear processes in stars, the mechanisms responsible for supernovae, and matter and magnetic field distributions in our galaxy (ref. 7).

Because these particles are strongly interacting, small amounts of atmosphere create backgrounds within which the primary information can be lost. This factor, together with the long exposure time necessary to accumulate significant amounts of information regarding the high-energy end of the spectrum, makes satellites the natural vehicle for the study of cosmic rays.

Man's search for knowledge of and control over his environment has led him into the realm of the very small, and his advances have been intimately related to his ability to create and use sources of higher and higher energies. Cosmic rays afford one such source. While a 200-GeV proton beam should be operational early in the 1970's and a 200-GeV center-of-mass facility could be available in the late part of that decade, cosmic rays reach well beyond the range of these machines. Relatively simple orbiting facilities could answer some extremely important questions in the field of high-energy physics. We could easily measure certain correlations among transverse and longitudinal momenta, multiplicity, and total energy, and match these measurements against the predictions of the multiperipheral theory, thus settling whether it is valid or not. The measurement of the proton-proton total cross section as a function of energy, done to 5 percent statistics, would establish the asymptotic behavior of the interaction*—another quantity of extreme significance. Proton-proton differential cross sections at high energies would settle the argument between the optical and Regge Poles theories (the former predicts that the diffraction peak

*Recent cross-section measurements at 706 eV tend to indicate that we may have been overly optimistic in expecting asymptotic behavior in the few hundred GeV region. (Note added in proof.)

stays constant, and the latter leads one to expect the peak to shrink as log E). Another set of questions to which the answers are within reach is: Does the transverse-momentum distribution law change at very high energies? How do weak interactions behave at these energies? Are there heavy particles being created with large transverse momenta as some Earth-based experiments seem to indicate?

While unmanned payloads can study cosmic rays, a relatively small increment in instrumentation, together with the versatility made available by the use of man to rearrange and service the hardware, would give us an experimental facility that would also provide vital information in the field of high-energy physics in the energy region below 10^{15} eV. (This would involve alinement of massive instruments to an accuracy of within a few microns over distances of many meters.)

Cosmic ray physics, together with the questions posed above, could be researched by use of only one major piece of equipment: a superconducting magnet of 2 to 3 meters diameter. The operation of this magnet would require either periodic supplies of liquid helium, or the development of a liquid-helium refrigerator, or better superconducting alloys. Success in the latter two will be of momentous consequence on Earth as well as in space. Complementing the magnet, there would be a liquid-hydrogen target, an energy-measuring device, and instruments such as proportional wire chambers, digitized readout spark chambers, solid Cerenkov counters, plastic scintillators, etc.

A second magnet and the addition of a streamer chamber at a later time will be possible and highly desirable. It must be emphasized that the key to a versatile facility is the periodic presence of man to rearrange experiments and service the hardware as needed. Operation will be automatic.

We feel that such a space station will continue to make important contributions in the study of high-energy and cosmic ray physics for the next 10 to 15 years, and that the equipment, once in orbit, could be used later in other facilities.

BEHAVIOR OF SOLIDS, LIQUIDS, AND GASES IN ZERO-G

(The Materials Science and Processing in Space white paper, found in appendix H, describes in considerable detail the behavior of solids, liquids, and gases under zero-g conditions.)

Our understanding of the physics of materials can benefit in two major ways from the zero-g environment: (1) The pressure in a fluid can be made uniform throughout the container, and (2) structures and materials do not need to support their own weight. The uniformity of pressure in a fluid is particularly important in experiments on phase transitions and fluctuations—a field currently of wide interest. As a specific example, we can cite the lambda transition in liquid helium, where the gravity-induced pressure gradient smears the transition temperature over regions so wide that studies of thermodynamic properties cannot be made as close to the lambda point as desired. In general, phase transitions in Earth-based experiments extend over a range of temperatures because the pressure varies throughout the fluid. Uniformity of pressure in a fluid may also be useful in studying the dependence of chemical reaction rates on pressure (refs. 8 to 10). While gravitational energy terms are small in comparison to the electromagnetic binding forces in materials, the absence of the former may produce interesting effects.

For instance, the crystal surface structure of drops allowed to solidify under zero-g conditions, free of any contact, is of long-standing interest to crystallization theory. The dynamics of these drops, suspended in free fall, can also be studied.

Experiments of this type could make use of a common, man-operated, physical sciences laboratory. With such a laboratory in space, experiments that are identified late in the space station planning could be added without too much additional effort. The presence of man also permits changes in experiments as new directions for research are identified.

RELATIVITY, COSMOLOGY, AND GRAVITATION PHYSICS

The importance of experiments in general relativity is that they are concerned with the large-scale physical laws that determine the

structure and behavior of the entire universe. There are some experiments in this field that can be performed on the Earth (refs. 11 to 13); however, there are other experiments that can only be done in space. A few have already been identified, and further space experiments will certainly be defined in the future. Most, if not all, of the candidate experiments could probably be automated. The justification for their inclusion in manned missions is that they could be simpler (and perhaps more effective) if operated by man. Some of these experiments, and the part that man plays in them, are listed below.

SPACE STATION EXPERIMENTS

Starlight Deflection Experiment

This experiment employs a small coronagraph to measure the relativistic deflection of starlight passing near the Sun, with much greater precision than can be done from the Earth because of atmospheric limitations. The justification for the experiment is that if it were precise enough, it might discriminate between the Brans-Dicke and Einstein theories of relativity. There is some disagreement among theorists that this experiment can discriminate among different theories of gravitation (ref. 14), for there is a heuristic derivation of this effect which is based only on the principle of equivalence and special relativity (ref. 15). However, the validity of this type of derivation has been seriously questioned. Indeed, in the original paper by Brans and Dicke (ref. 16), they show that their theory leads to a value for the deflection of starlight which is different from the value of Einstein's general relativity theory.

Thus, this is an important experiment not only because it might discriminate between two conflicting theories, but also because it may answer some theoretical questions concerning the proper way to do certain relativistic calculations. High precision is desirable, for the Brans-Dicke theory contains an adjustable parameter, and the higher the experimental precision the more meaningful are the bounds that can be placed on this parameter.

A man can perform the careful collimation of the telescope, which will enable it to measure star positions to the required high precision. The presence of man also permits film to be used as the

data-collecting medium, which significantly simplifies telescope design and data reduction.

Isotropy and Spectrum of the Cosmological Blackbody Radiation

Many of the possible detectors for the radiometers used in this experiment require cryogenic cooling to achieve the desired signal/noise ratio. The cryogens needed will probably be available on a manned space station. The availability of man will also enable a much simpler experiment design, because the calibration procedures need not be automated. Again, the presence of man will permit long-term measurements that will yield good statistics.

LUNAR EXPERIMENTS

Of the many man-deployed experiments that will be developed on Apollo missions, two will yield information that will be useful for relativity theory: lunar gravimeters, and laser retroreflectors.

The discovery of gravitational waves on the Moon would be an extremely significant event. A sensitive lunar gravimeter placed on the lunar surface will provide useful selenological data and allow the Moon to be used as an antenna for the detection of these waves. The availability of men on the Moon in the mid-1970's will enable placement and adjustment of more advanced versions of this instrument. Manned maintenance will keep these gravimeters operating over the long periods necessary to establish whether there is a significant number of coincidences between possible gravitation wave events on the Moon and on Earth.

Laser retroreflectors are precision optical devices that can return laser beams to Earth to enable precise tracking of the Moon's motion. This information would yield a variety of data, including information on cosmological questions such as the possibility of variation in the gravitational constant. Men will place these instruments on the Moon early in the Apollo program, but replacement will be needed throughout the 1970's as the reflectors become eroded by micrometeorites. This replacement will be necessary to insure that reflectors are available for the 8 to 10 year period needed to obtain sufficient data to determine if the gravitational constant G changes as the universe expands.

MICROMETEOROID MEASUREMENTS

Identifying the differences between asteroid and comet material may provide clues to the history of formation of the solar system. Since the relative speeds between the Earth and interplanetary matter are about 15 km/sec., sample collection will consist of deploying extremely pure traps (i.e., tungsten blocks), and recovering, resealing, and delivering them to Earth laboratories. In situ analysis by onboard ionization and mass-spectrometry may also be feasible. Manned versus unmanned operating modes should be determined by cost effectiveness, convenience, and reliability.

A related field is the study of the gegenschein, zodiacal light, and Earth-Moon libration points. These phenomena all consist of sunlight scattered from interplanetary material and so give clues about its distribution in the solar system. Man is quite useful in this area because the equipment required, small wide-angle cameras, is so simple. This is an example of an experiment that may not justify an unmanned launch because it is so small it can be carried into space on a manned launch at essentially no cost. Also, it makes use of man's ability to calibrate and repair equipment, identify new targets for study, and re-program the observing schedule.

MAGNETOSPHERIC PHYSICS

The Van Allen belts, aurora, auroral precipitation, ionospheric disturbances, magnetic storms, the magnetosheath, the magnetospheric tail, solar wind, and solar flares are all separate manifestations of a more comprehensive phenomenon which, for lack of a better name, can be called solar system weather. To date, however, they have been studied separately because initial requirements have been for detailed and specific descriptions of the morphology of these phenomena. Large numbers of unmanned satellites and space probes have been used to explore and determine just what the environment of Earth is. (The existence of the Van Allen belts was not proved until 1958, while the solar wind was first probed in 1962!) Because of the United States exploratory program, man now has a reasonably complete picture of his environment. What is lacking, however, is a comprehensive understanding of the interplay of all these separate phenomena and their eventual relation to the Sun and solar phenomena (ref. 17).

To obtain this synoptic view of the fundamental interaction of Earth and Sun, a manned orbiting laboratory can be most useful. It seems reasonable to assume that the charting of the environment will continue to be done by highly specialized unmanned satellites, because the detectors have been developed, are generally small, and because of the desire to have many of them in a network providing world-wide coverage. These instruments could be taken to the manned station and then launched individually into orbit, if economic considerations warrant this deployment mode.

The orbiting laboratory could conduct experiments within the magnetosphere which would provide valuable information on the dynamics of the region. Except for the Starfish event that created an artificial Van Allen belt, there have been no experiments of this type performed in space. It is possible, for example, to inject electrons into the magnetosphere and follow their motions along the magnetic field lines. It is even possible in this way to form an artificial aurora. Environment-modifying experiments of this type could study wave propagation, particle diffusion, and the dynamic coupling of magnetospheric phenomena. Subsatellites offer a wide range of experimental opportunities. Controlled from the laboratory, these might be used to probe regions inaccessible to the station and to study the wakes of vehicles, radio transmission characteristics, wave-particle interactions, and whistler propagation (ref. 18).

CRITICAL ISSUES

The realization of the goals described in this paper are not dependent on major technical innovations. Neither is there a reason to expect that the goals outlined in the four previous sections (pp. 74-80) will undergo substantial changes. Implementation by manned or unmanned modes will depend on technological developments, cost, and political considerations.

High-energy and cosmic ray physics must be given a different priority. This program is by far the most ambitious one in terms of cost, weight, and power consumption. Particle detection techniques may undergo radical changes, and continuing accelerator and theoretical work could make today's questions irrelevant 10 years hence. It is with these facts in mind that we present "Conclusions and Recommendations."

ORBITAL CONSIDERATIONS

High-energy and cosmic ray physics.—An orbit providing low radiation background is preferable, but not imperative.

Behavior of matter in zero-g.—Because of atmospheric drag, the lowest allowable orbit will depend on the requirements of the experiment. The table below shows values calculated for the Apollo VII command and service modules.* Accelerations are given in g's, and d is the distance a body would move if subjected to the respective constant acceleration for 5 minutes.

Altitude, km	a/g	d, cm
200	5.7×10^{-7}	25.0
300	5.6×10^{-8}	2.5
400	8.3×10^{-9}	0.4

Gravitation physics.—No orbital preference. The experiment on starlight deflection by the Sun (see p. 77) depends on observations over long periods, but not on a continuous basis; thus a Sun-synchronous orbit is unnecessary.

Micrometeoroid measurements.—No orbital preference.

Magnetospheric physics.—No orbital preference for the station. It would be used to launch and service small probes that will be part of a global network.

CONCLUSIONS AND RECOMMENDATIONS

We feel that if technology, cost considerations, and/or national goals, make available a manned capability, the presence of man in space will make possible the implementation of the programs described above. Man will deploy, calibrate, and repair instrumentation as needed. His role as an observer will be particularly useful while working on the behavior of matter under zero-g conditions. Experimental programs described in previous sections of this paper could be very attractive if integrated within a large manned facility. The particle physics facility should be separate from the main

*R. W. Newsome, private communication, 1968.

station, because its electromagnetic noise output may provide an intolerable background for some of the other experiments described. Only periodic visits will be necessary, and the key to its success will be the versatility introduced by having men rearrange the hardware as necessitated by the established program and new developments in the field.

We recommend that NASA follow progress in this field quite closely so that the programs and facilities will not be obsolete when orbited.

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